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A SHORT STUDY OF LARGE ROTARY FORGED CYLINDERS

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June 1979

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The Integrated Forging Line was used to produce steel for the Advanced Breech Technology program. Cylinders were rotary forged from cast hollow ESR and from vacuum degassed steel. Anomalies in the data prompted a more detailed metallurgical study. The results are presented. Satisfactory properties were produced from the vacuum degassed steel. However, the very light forging reduction coupled with the very rapid and short austenitizing inherent in the Selas heat treatment system were inadequate to develop satisfactory properties

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in the cast ESR steel.

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INTRODUCTION

The Integrated Forging Line was used to produce experimental breech ring forgings for the advanced breech technology program. A hollow ESR cast cylinder was rotary forged and heat treated; subsequently, a forged hollow vacuum degassed cylinder was rotary forged and heat treated. In evaluating the material produced, anomalies appeared. This prompted the further, more detailed evaluation which is presented herein.

PRODUCTION OF FULL-SIZE CYLINDERS

Hollow ESR Ingot

The starting preform was a cast hollow ESR ingot of gun steel, produced by Cabot Corporation, with a nominal OD of 20" (actually tapered from 19-1/2" to 20-1/2") and a trepanned ID of 9.5". The original cast ID was 7.5". It was enlarged because the original intent was to use the ingot to produce a truncated 8" M201 tube. It was decided to use the material to produce a cylindrical forging from which to manufacture several breech rings. Previous experience with rotary forging of hollow ESR ingots was limited to the forging of one 105mm M68 tube from a smaller cast ingot, from which the results were comparable to those obtained with normal production rotary forge practice.

The preform was heated in the Cheston induction heating system and rotary forged over a 5.5" water cooled mandrel to an OD of approximately 17". Because of the large amount of sinking, i.e., free movement of the ID of the ingot prior to contacting the OD of the mandrel, the actual ID produced at each end was greater than 5.5". However, the preponderance of the ID contacted the mandrel during forging. The total forging reduction was very light, viz., about 1.15:1.

Heat treatment was performed in the Selas horizontal continuous heat treating system as shown in Table 1. In quenching hollow cylinders, the practice commonly used is to quench the ID first for a designated period (viz., ID Lead Time) and then quench both the ID and OD together for an extended period. In this case, the ID was quenched for approximately one minute longer than the OD. (Note: The ID is quenched by passing a large volume of water through the bore, whereas the OD is quenched by a water spray simultaneously along the entire length of the cylinder.)

After the initial heat treatment, a discard corresponding in length to one wall thickness was taken from each end and transverse mechanical properties measured at the mid-radius of the adjacent material. Because the results were unsatisfactory (Table 2), an additional discard was removed from each end and material which definitely had contacted the mandrel during forging was tested. Unfortunately, this also was unsatisfactory (Table 2). The microstructure at the mid-wall of both the top and bottom showed evidence of ferrite and bainite (Figs. 1 and 2).

The inadequacy of the material can also be seen in the variation in longitudinal strength taken from the OD, mid-wall and ID of the initially heat treated cylinder (Table 3). An analysis of the microstructure at the OD, mid-wall and ID (Figure 3) suggested that the original heat treatment was inadequate in terms of both austenitizing and quenching.

There was evidence of ferrite showing that the cylinder had not been fully austenitized, and of bainite, showing that the material transformed to austenite had been inadequately quenched, since martensite is the desired product. Therefore, the remainder of the cylinder was passed through the Selas system a second time at a slightly lower speed and tempered at a slightly lower temperature to raise the yield strength. Discards were removed, and the material was again tested. The results were still unsatisfactory in terms of mechanical properties (Table 2) and microstructure (Figure 4).

Additional material evaluation and testing were performed on smaller sections from the cylinder. These tests and results are described later.

Forged Vacuum Degassed Preform

Several forged vacuum degassed preforms were available for use in producing 8" M201 tube forgings as part of an MM&T program. Because of the lack of success with the hollow ESR, one was diverted to use in this program. It had been produced by National Forge Co. from a 61" ingot by press forging (solid) and machining into a hollow cylinder with nominal dimensions of 20" OD and 8.5" ID.

It was rotary forged into a 17" OD x 5.5" ID cylinder in the same manner as the hollow ESR ingot and heat treated in the Selas system as shown in Table 4.

After heat treating, a discard was taken from each end and the material was evaluated. The results were outstanding in terms of the combination of transverse mechanical properties obtained and in the consistency of the mechanical properties through the wall as shown by the longitudinal data (Table 5). The microstructures at both ends and through the wall show predominantly martensite at the OD with a larger amount of bainite at the mid-wall and ID (Figures 5 and 6). However, the yield strength was higher than desired by about 10-11 ksi. Re-tempering in the Selas system to reduce the strength by such a small amount is extremely difficult. The tempering temperatures required are such that small changes can result in large changes in yield strengths. If the yield strength is reduced too much, then a complete re-heat treatment is required.

Therefore, a 30" section, sufficient to provide one breech ring and test material, was retempered at 1120°F for 3 hours at temperature in a standard furnace, and water quenched. The results were satisfactory (Table 6). Subsequently, three additional sections were reheat treated in the same fashion with similar satisfactory results (Table 6). (The yield strength obtained in Cylinder 2 suggests that that cylinder may have received a slightly different re-tempering treatment). The microstructure in all cases was a mixture of martensite and bainite (Figure 7).

<u>Additional Work - Hollow ESR Ingot</u>

Because of the relatively poor properties and unusual microstructure obtained with the rotary forged hollow ESR ingot, several heat treating tests were conducted without additional forging. The problem appeared to be associated with several factors:

1. Structure and segregation in the ingot.

2. Very light forging reduction which did not break up the structure and segregation.

3. Very short time at relatively low austenitizing temperature, which is a feature of the Selas system, and in this case, appears to have been too short to completely austenitize the entire cross section because of the segregation.

4. Quenching practice which developed bainite rather than martensite.

The combination of these factors resulted in a macro-structure with a strong, coarse, dendritic pattern and a microstructure consisting of ferrite and bainite.

Initially, a one inch thick disc from the rotary forged cylinder was cut in half; one half was normalized and heat treated while the second half was heat treated without normalizing. After normalizing, both sections were heat treated together. The specimens were treated as follows:

Normalize (Section 1)

1700°F - 2 Hrs. - Air Cool

Harden (Both Sections)

1550°F - 1 Hr. (at temp) Water Immersion Quench

Temper (Both Sections)

1100°F - 1 Hr. (at temp.) - Water Immersion Quench

The mechanical properties were excellent (Table 7) and the microstructure was martensitic (Figure 8). The normalizing had no apparent effect.

To test the possibility of improving the properties in a full wall thickness, a 12" length of the cylinder was heat treated, with emphasis on extending the austenitizing time. The heat treatment was essentially the same as that for the non-normalized disc above, except that the austenitizing time, prior to hardening, was 6 hours. In this test there were two peculiarities. As shown in Table 8, a chordal section had been removed from the cylinder prior to heat treatment. Also, the quench was performed horizontally rather than vertically with the flat face being quenched first. Thus, Specimen 5, which is a mid-wall specimen from the forging standpoint, is actually an OD specimen as far as the quench is concerned. Also, Specimen 3 was subjected to a less than adequate quench because of the quenching technique. The mechanical properties obtained are also shown in Table 8. Despite the excellent mechanical properties, there is still evidence of ferrite and the microstructure is predominantly bainite (Fig. 9) with the amount of ferrite being greater at the mid-wall which experienced the least forging deformation.

DISCUSSION AND CONCLUSIONS

The original intent of this work was to produce material which could be used for advanced technology breech rings. This was accomplished with the use of the vacuum degassed preform. Despite the fact that the rotary forge reduction was very light, the overall reduction from the ingot stage was heavy. Thus, as is seen in Figure 10, while there is evidence of a flow pattern, the cast structure is broken up, and the mid-wall is essentially the same as the ID and OD.

This is not true for the rotary forged hollow ESR ingot. There, the only forging reduction was that imposed during the rotary forge operation. As seen in Figure 11, this was not enough to break up the dendritic structure. Figure 12 also shows the uneven forging deformation experienced through the wall. This mid-wall shows less alignment of structure than the OD or ID, indicating less working.

While the residual cast structure undoubtedly contributes to the problematic mechanical properties obtained with the hollow ESR, it is not acting alone. The final heat treatment test on the short full wall cylinder demonstrates that even with the light working, it is possible to develop outstanding mechanical properties.

The problem with the hollow ESR appears to be several fold. Ingot structure with an attendant segregation pattern is established during the solidification process. Heavy reduction, i.e., 3-5 to 1, should break up this structure and allow the generation of acceptable mechanical properties. This was demonstrated by the aforementioned 105mm M68 tube. However, light reductions do not break up the structure, nor affect the segregation pattern. This makes the development of good properties more difficult, but not impossible. When heat treated in the horizontal continuous furnace, where austenitizing temperatures are deliberately low and times are deliberately short, the residual ingot structure controls the mechanical properties. However, if austenitizing times can be increased significantly, and an adequate quench can be applied, a degree of homogenization can be developed, and outstanding properties can be generated, even at the mid-wall of heavy sections.

TABLE I

HOLLOW ESR
PROCESSING HISTORY

Starting Material - Cast hollow ESR ingot, 20" (nom.) OD (as-cast) x 9.5" ID (machined). Produced by Cabot Corp.

Forging - Rotary Forge to 17" OD x 5.5" ID

Heat Treat - Heat treated in Selas System

Workpiece Speed - .12 Ft/min.

Austenitizing Exit Temp. - 1550°F - 1600°F

Water Spray Quench

ID Lead Time - 1 Min.

ID (Total) - 21 Min.*

OD (Total) - 20 Min.*

Tempering Temperature - 1125°F

Water Spray Cool

Reheat Treat - Reheat treated in Selas System

Workpiece speed - .11 Ft./min.

Austenitizing Exit Temp. - 1560°F - 1595°F

Water Spray Quench

ID Lead Time - 1 Min.

ID (Total) - 21 Min.

OD (Total) - 20 Min.

TABLE I (Continued)

Tempering Temperature - 1110°F

Water Spray Cool

*Originally quenched for 16 min. ID and 15 min. OD, then after a hardness check, quenched for an additional 5 min. on the OD and on the ID.

TABLE 2
HOLLOW ESR
ROTARY FORGED
SELAS HEAT TREAT

	YS	RA	$C_v(-40°F)$
1. Initial Heat Treat			
a. Initial Test			
Transverse - Top*	138 ksi	47%	18 ft-lbs
	144	45	19
	137	45	14
	138	45	14
Transverse - Bottom*	160	42	22
	145	41	32
	140	22	16
	140	39	19
b. Retest			
Transverse - Top	134	49	15
	138	48	17
Transverse - Bottom	136	41	15
	141	43	21
2. Reheat Treat			
Transverse - Top**	149	41	13
	159	43	9

*Top and Bottom signify the first and last ends through the rotary forge and the Selas heat treat system.

**Only one end tested.

TABLE 3
HOLLOW ESR
ROTARY FORGED
SELAS HEAT TREAT

	YS	RA	Cv(-40°F)
Longitudinal - Top			
OD	152 ksi	54%	51 ft-lbs
Mid	139	53	35
ID	152	59	44

TABLE 4

VACUUM DEGASSED

PROCESSING HISTORY

Starting material - Forged (from 61" ingot), machined
vacuum degassed preform, 20" OD x 8.5" ID.
Produced by National Forge Co.

Forging - Rotary Forge to 17" OD x 5.5" ID

Heat Treat - Heat treated in Selas System

Workpiece Speed - .11 ft/min.

Austenitizing Exit Temp. - 1550°F - 1590°F

Water Spray Quench

ID Lead Time - 1 min., 10 sec.

ID (Total) - 21 min., 10 sec.

OD (Total) - 20 min.

Tempering Temperature - 1100°F

Water spray cool

TABLE 5

VACUUM DEGASSED (FORGED)
ROTARY FORGED
SELAS HEAT TREAT

		YS	RA	C_V(-40°F)
Transverse - Top*		151 ksi	47%	34 ft-lbs.
		158	42	31
Transverse - Bottom*		156	43	37
		154	44	37
Longitudinal - <u>Top*</u>				
	OD	159	61	57
		159	64	55
	MID	159	62	58
		159	61	58
	ID	159	63	53
		159	63	54
Longitudinal - <u>Bottom*</u>				
	OD	155	62	58
		154	63	62
	MID	155	62	61
		155	63	60
	ID	156	62	61
		155	65	57

*Top and Bottom signify the first and last ends through the rotary forge and the Selas heat treat system.

TABLE 6

VACUUM DEGASSED (FORGED)
ROTARY FORGED
SELAS HEAT TREAT
RETEMPER - STANDARD FURNACE

	YS	RA	C_V(-40°F)
Cylinder 1 - Transverse	148 ksi	47%	40 ft-lbs.
	150	47	38
Longitudinal	154	64	55
	150	63	63
Cylinder 2 - Transverse	156	44	39
	154	41	39
Cylinder 3 - Transverse	149	49	38
	150	35	42
Cylinder 4 - Transverse	148	48	46
	146	51	40

Retemper each piece - 1120°F - 3 Hrs. at temp.

#1, 2 - 30" long cylinder

3, 4 - 26" long cylinder

TABLE 7

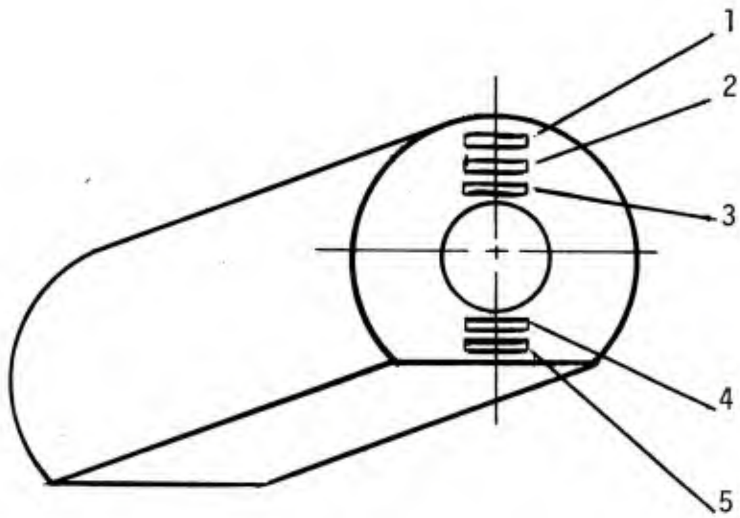
HOLLOW ESR
ROTARY FORGED
SELAS HEAT TREAT
REHEAT TREATED IN SMALL SECTIONS

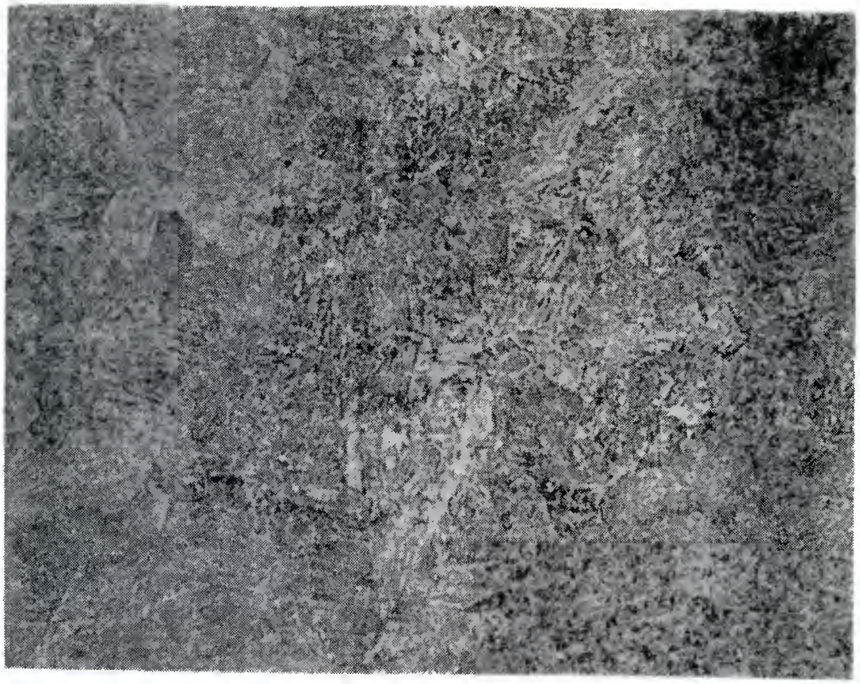
	YS	RA	C_v(-40°F)
Transverse			
Normalized	166 ksi	46%	35 ft-lbs
	164	45	32
Not Normalized	162	49	39
	161	47	37

TABLE 8

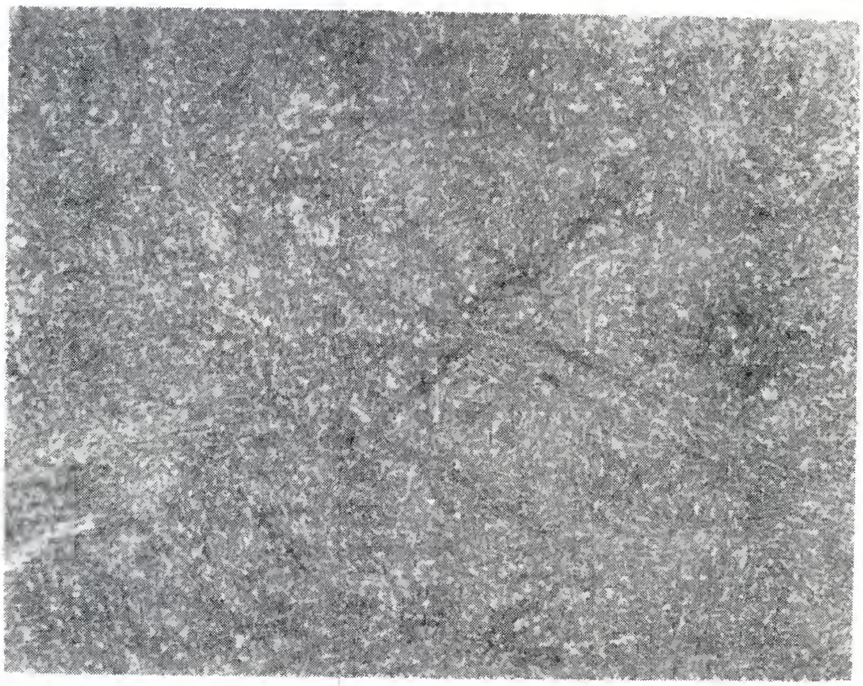
HOLLOW ESR
ROTARY FORGED
SELAS HEAT TREAT
REHEAT TREATED IN FULL WALL THICKNESS SECTIONS

SPECIMEN	YS	RA	C_V
1	152 ksi	52%	44 ft-lbs.
2	152	44	41
3	150	36	28
4	150	39	39
5	153	39	39





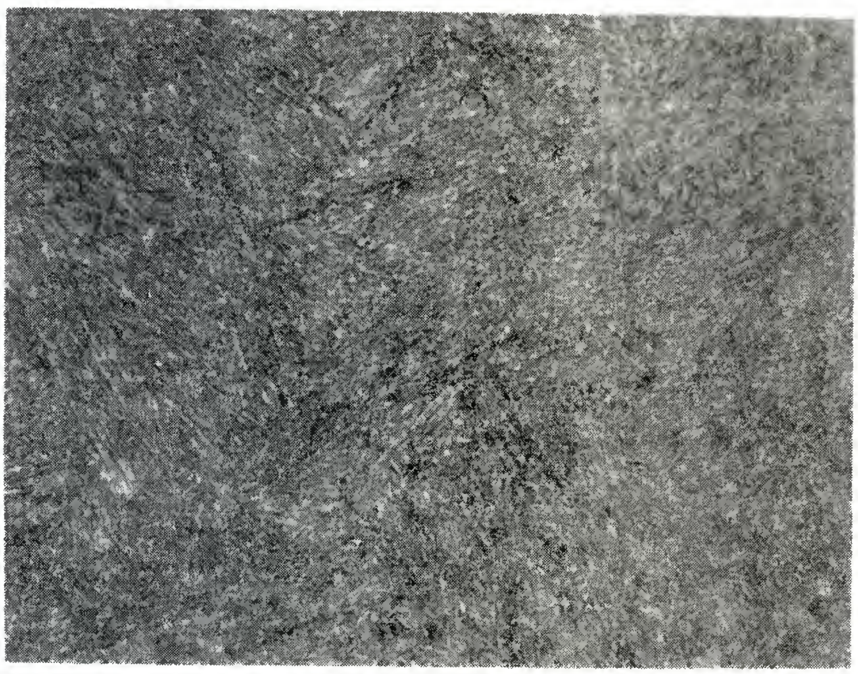
1(a) - Ferrite patches



1(b) - Predominantly bainite

FIG. 1 - Microstructure at mid-wall of heat treated rotary forged hollow ESR Cylinder (Top) - 1000X (See Table 2)

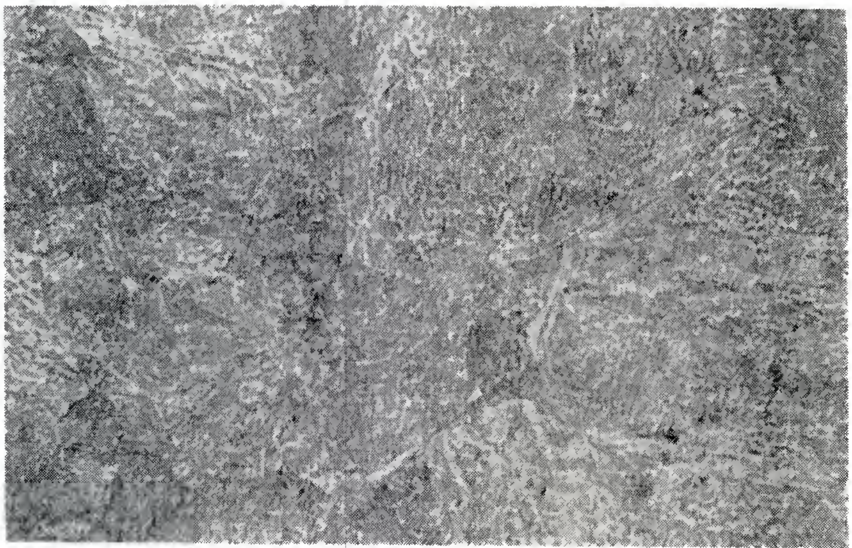
2(a) - Ferrite patches



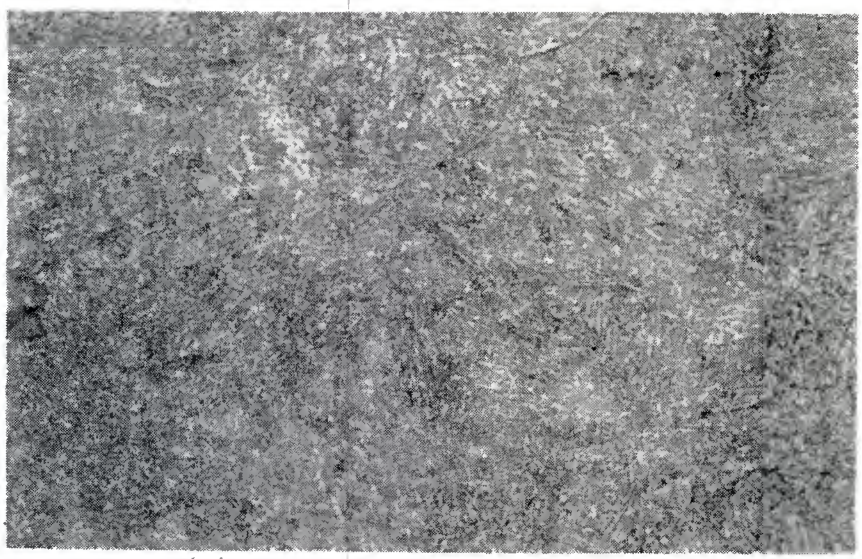
2(b) - Predominantly bainite

FIG. 2 - Microstructure at mid-wall of heat treated rotary forged hollow ESR cylinder (Bottom) - 1000X (See Table 2)

3(a) OD - Predominantly bainite



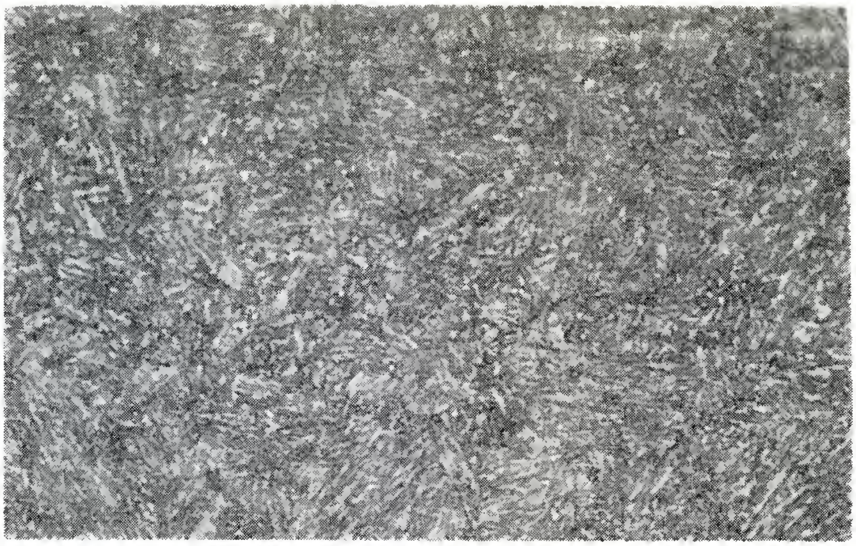
3(b) Mid-wall - Ferrite patches



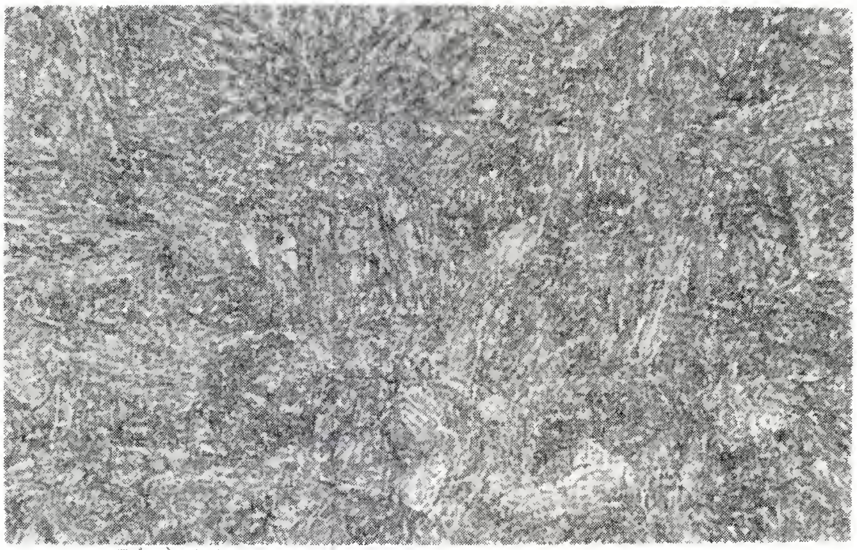
3(c) ID - Predominantly bainite

FIG. 3 - Microstructure of heat treated rotary forged hollow ESR cylinder (Top) - 1000X (See Table 3)

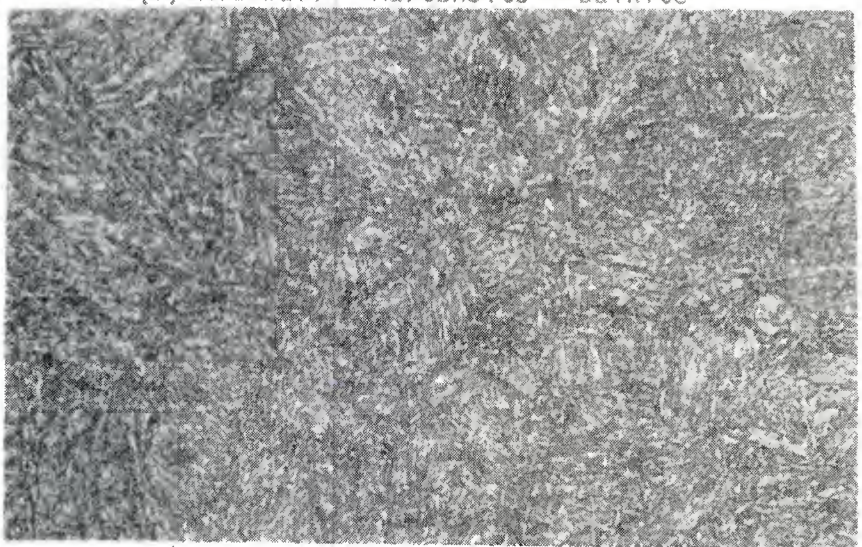
FIG. 4 - Microstructure at mid-wall of reheat treated rotary forged hollow ESR cylinder (Top) - 1000X (See Table 2)



5(a) OD - Martensite - Bainite

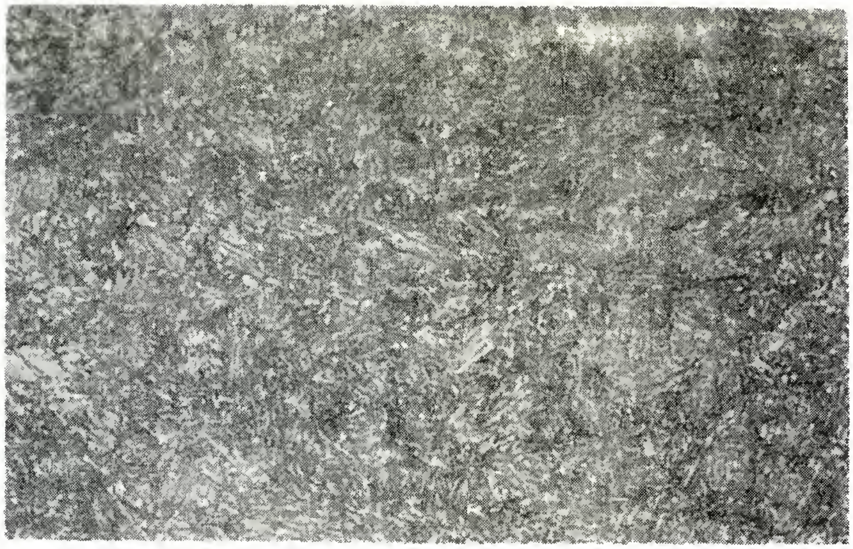


5(b) Mid-wall - Martensite - Bainite



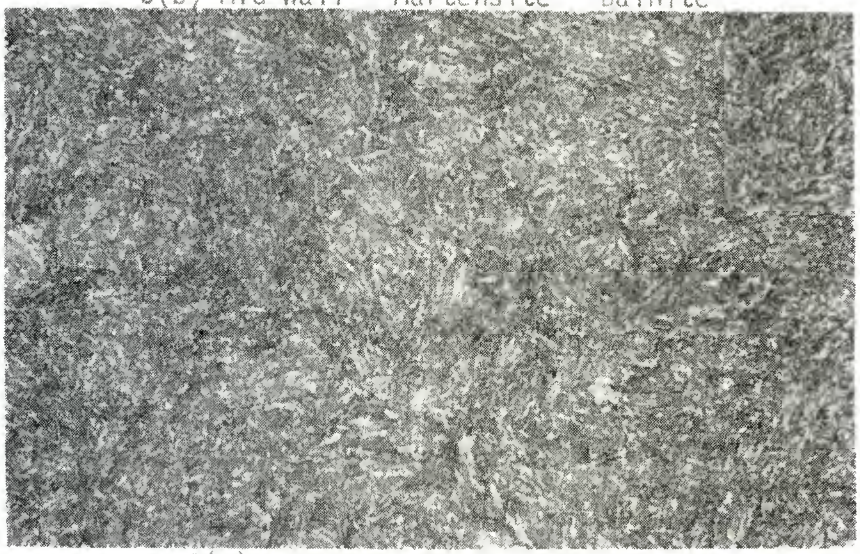
5(c) ID - Martensite - Bainite

FIG. 5 - Microstructure of heat treated rotary forged vacuum degassed cylinder (Top) - 1000X (See Table 5)



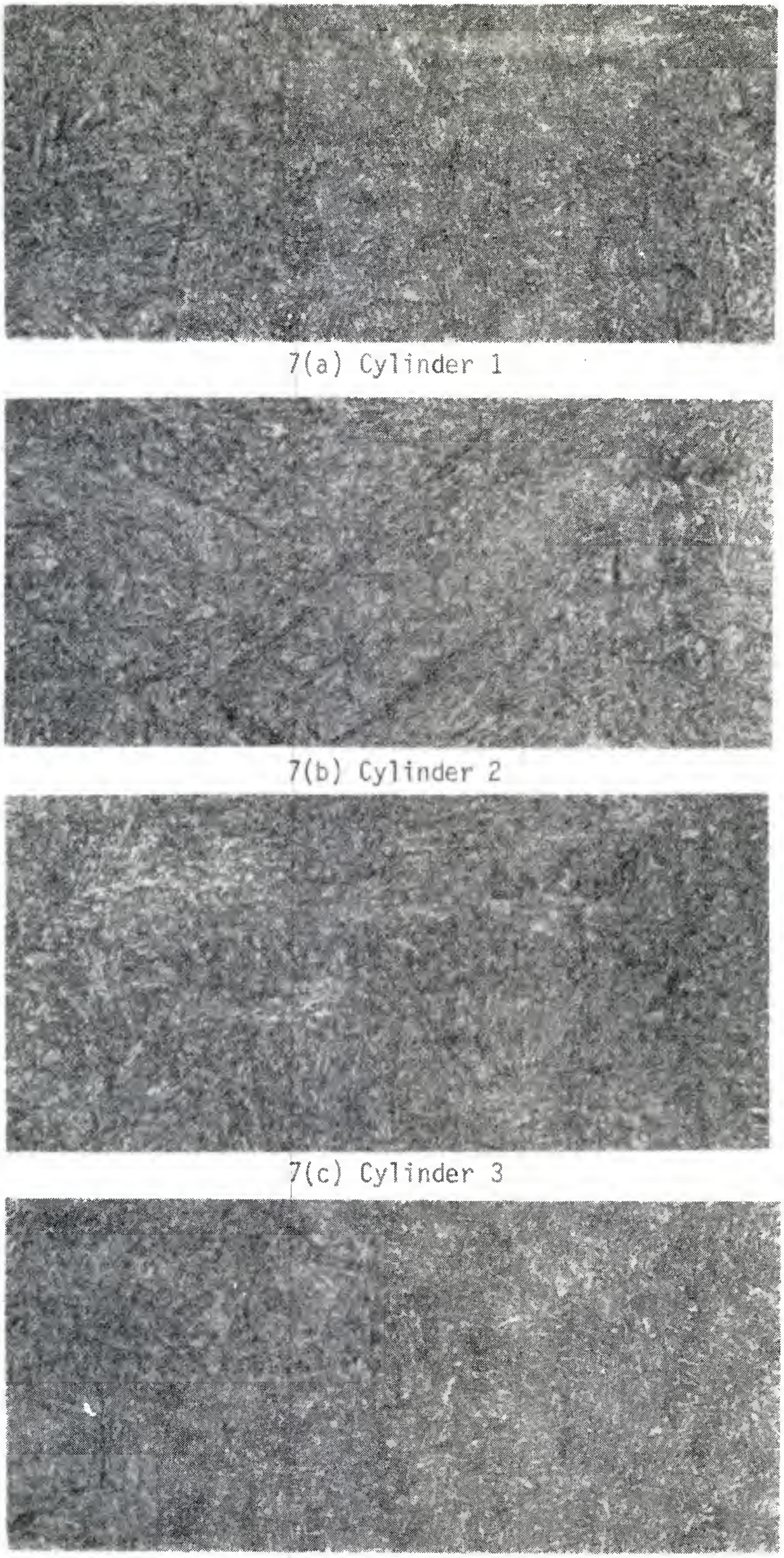
6(a) OD - Martensite - Bainite

6(b) Mid-wall - Martensite - Bainite



6(c) ID - Martensite - Bainite

FIG. 6 - Microstructure of heat treated rotary forged vacuum degassed cylinder (Bottom) - 1000X (See Table 5)



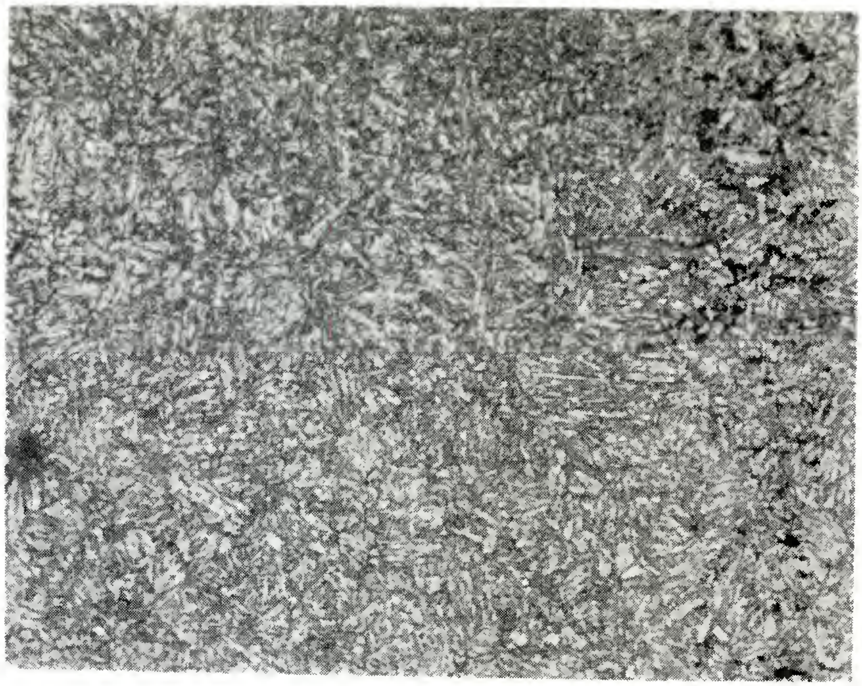
7(a) Cylinder 1

7(b) Cylinder 2

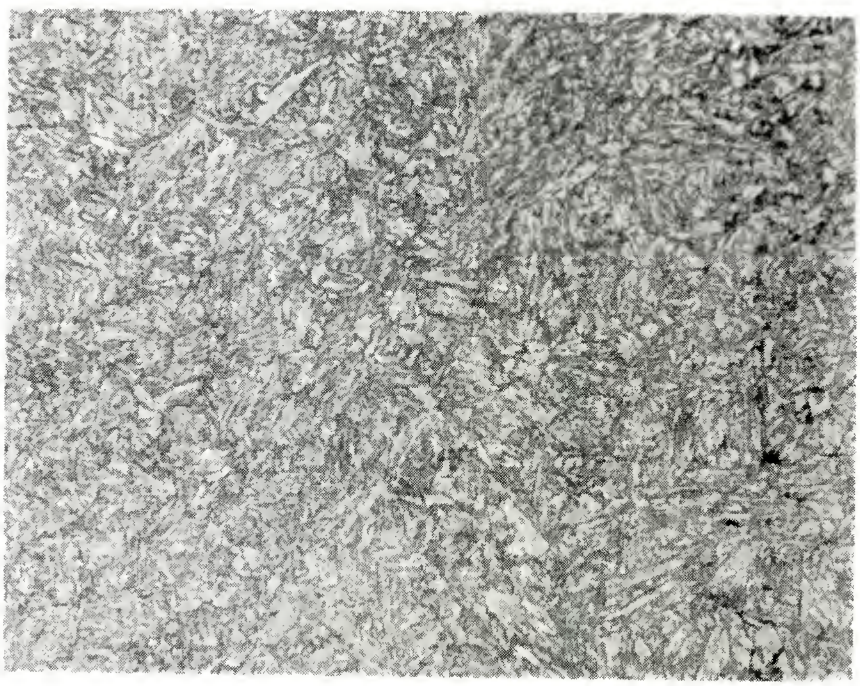
7(c) Cylinder 3

7(d) Cylinder 4

FIG. 7 - Microstructure at mid-wall of reheat treated rotary forged cylinders - Martensite-Bainite 1000X (See Table 6)



8(a) Normalized

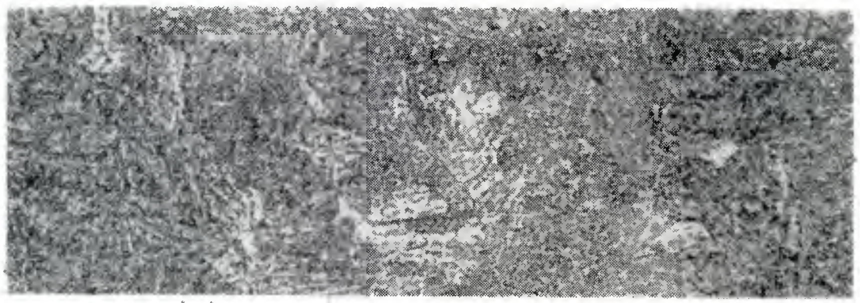


8(b) Not Normalized

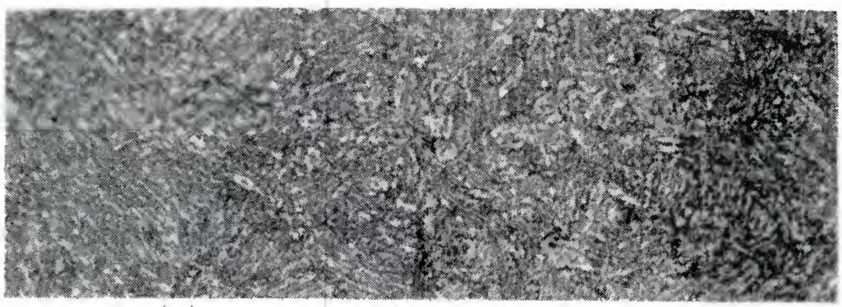
FIG. 8 - Martensitic microstructure of (a) normalized and heat treated, and (b) heat treated section of rotary forged hollow ESR ingot - 1000X (See Table 7)

9(a) Section 9-1 - Martensite-Bainite

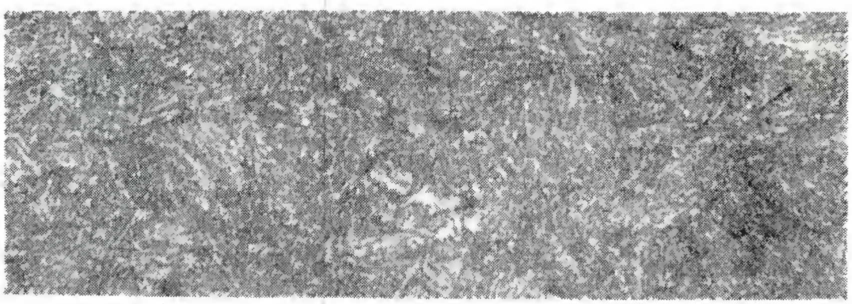
9(b) Section 9-2 - Ferrite Patches



9(c) Section 9-3 - Ferrite Patches



9(d) Section 9-4 - Martensite-Bainite

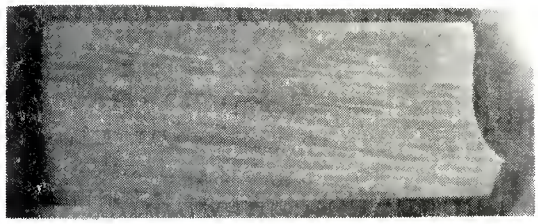


9(e) Section 9-5 - Martensite-Bainite

FIG. 9 - Microstructure of reheat treated rotary forged hollow ESR cylinder - 1000X (See Table 8)

10(a) OD

10(b) Mid-wall



10(c) ID

FIG. 10 - Flow lines at (a) OD, (b) Mid-wall and (c) ID of vacuum degassed cylinder (Top).

11(a) OD

11(b) Mid-wall

11(c) ID

FIG. 11 - Flow lines at (a) OD, (b) Mid-wall and (c) ID of rotary forged vacuum degassed cylinder (Bottom).

12(a) OD

12(b) Mid-wall

12(c) ID

FIG. 12 - Dendritic pattern at (a) OD, (b) Mid-wall and (c) ID of rotary forged hollow ESR cylinder. (Note the greater compaction of the pattern at the OD indicating an uneven deformation during forging.)

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